

REPORT DOCUMENTATION PAGE				Form Approved OMB NO. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 21-02-2013		2. REPORT TYPE Related Material		3. DATES COVERED (From - To) -	
4. TITLE AND SUBTITLE Trip Report for M. Durand to France				5a. CONTRACT NUMBER W911NF-11-1-0297	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 611103	
6. AUTHORS Magali Durand				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of Central Florida Office of Research University of Central Florida Orlando, FL 32826 -0150				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211				10. SPONSOR/MONITOR'S ACRONYM(S) ARO	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) 59727-PH-MUR.1	
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
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15. SUBJECT TERMS Paris, Optical Phase Conjugation					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Martin Richardson
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			19b. TELEPHONE NUMBER 407-823-6819

## **Report Title**

Trip Report for M. Durand to France

### **ABSTRACT**

A collaborative experiment was made in Paris, between CREOL, University of Central Florida and LOA, Ecole Polytechnique, on filament interaction. Recent studies have proven that crossing two filaments can give interesting phenomena (plasma grating, energy exchange). In this collaborative work we study the possibility and the characterization of Optical Phase Conjugation (OPC) created by two counter propagating filaments interacting with a probe beam.



## ARO MURI "Light Filamentation Science"

Contract #: W911NF1110297

PI : Martin Richardson



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### **OPTICAL PHASE CONJUGATION BY TWO COUNTER PROPAGATING FILAMENT**

Participants: Magali Durand

Place: LOA, Palaiseau, France

Dates: 07/16 – 27/2012

Abstract: A collaborative experiment was made in Paris, between CREOL, University of Central Florida and LOA, Ecole Polytechnique, on filament interaction. Recent studies have proven that crossing two filaments can give interesting phenomena (plasma grating, energy exchange). In this collaborative work we study the possibility and the characterization of Optical Phase Conjugation (OPC) created by two counter propagating filaments interacting with a probe beam.

## 1/ Objectives of the Collaboration Visit

We intend to better understand the interaction of multiple filaments, which is MURI theme 3, more precisely to first understand the interaction of two filaments (MURI Topic 3.1). Previous results made in LOA have shown the interest of two filaments interacting. It has been proven that the resulting plasma grating from two interacting filament can be used to exchange energy between filament with an efficiency as high as 50 % [1]. This grating can induce a Doppler effect on a probe beam revealing the travelling of the plasma grating when the two pump pulses are chirped [2]. This grating was used also to study filamentation, and determined the plasma parameters (electronic recombination and electronic diffusion) of this particular type of plasma (weakly ionized plasma in dense atmosphere, 1 bar) [3].

We intend to study the efficiency of counter propagating filaments to perform optical phase conjugation. Filaments have already proven much more efficient for wave coupling (energy exchange) than the classical non linear optics. By using two filaments and a probe beam at an arbitrary angle to generate a conjugate beam, we put ourselves in the configuration of a degenerative four waves mixing to produce phase conjugation, see Figure 1. This four-wave mixing is degenerate in the sense that all four waves have the same frequency, and the non linear medium used is therefore “air”.

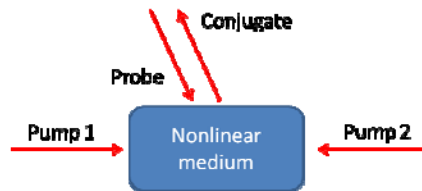


Figure 1 : Geometry of phase conjugation by degenerate four-wave mixing

We can also understand OPC by considering that the incoming probe wave interferes with one of the pump waves to form a spatially varying intensity distribution; which will be “imprint” by the non-linear response of the medium into a variation of the refractive index following the interference pattern [4]. In our case, this interference pattern can also be imprint into the plasma and give another variation of the refractive index by the plasma generation following the interference pattern. Those variations of the refractive index acts as a volume diffraction grating, which scatters the other pump wave to form the outgoing conjugate wave.

## 2/ Justification for the experiment outside of the lab

The Laser-Matter Interaction team (Interaction Laser-Matière – ILM) at the Laboratory of Applied Optics (Laboratoire d’Optique Appliquée – LOA) is an active collaborator in this MURI. Led by André Mysyrowicz this team is an expert in the domain of the phenomena induced by multiple filaments.

Furthermore, during the construction of the Multi-Terawatt Femtosecond Laser facility (MTFL), under the DURIP # W911NF1010491, a collaboration with this team was an effective way to keep progressing in the schedule of experiments for the MURI program.

### 3/ Technical description of studies

We used the commercial Thalès Alpha 100 laser system, which deliver pulses of 10 mJ, 35 fs with a cadence of 100 Hz at 800 nm. The laser beam was split into three beams, two pump beams which will create the two counter propagating filaments of 1.1 mJ each and a probe beam of 0.2 mJ. We base our experiment on the degenerative four waves mixing to create a conjugate beam, see Figure 2.

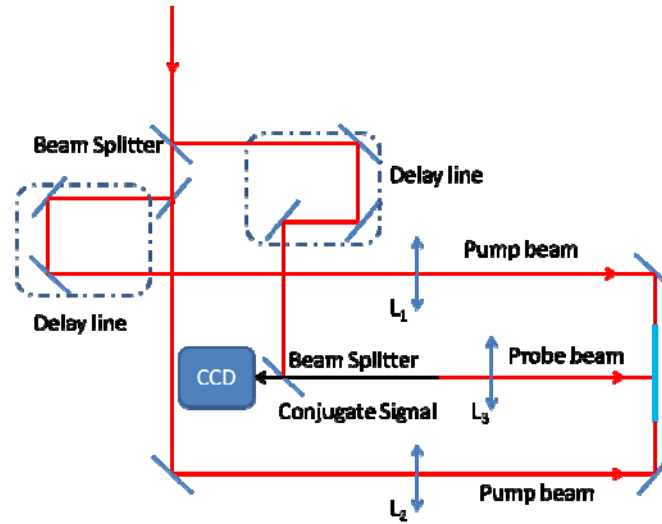


Figure 2 : Experimental set up, lenses  $L_1 = L_2 = 1$  m focal lens,  $L_3 = 15$  cm.

### 4/ Results

We were able to obtain a beam which propagates at the opposite direction of the probe beam. We set the probe beam for two different angles  $40^\circ$  and  $90^\circ$  with respect to the propagation axis of the filaments. For each angles, we obtain a signal beam which propagates in the opposite direction of the probe beam.

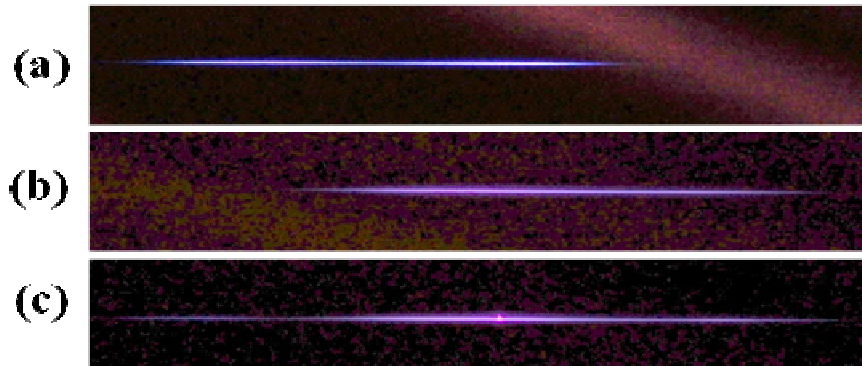


Figure 3 : Side view of the plasma emission from excited nitrogen inside the filament. (a) Pump 1 alone (b) Pump 2 alone (c) Pump 1 & 2. One can see a stronger emission at the point where the two filaments are interacting in time.

We then characterized this signal beam (conjugate beam) in a  $90^\circ$  geometry. The first striking properties of this conjugate beam is the fact that the beam is clean for default and Gaussian, see Figure 4. The conjugate signal appears to take the spatial properties of the filament instead of the probe beam.

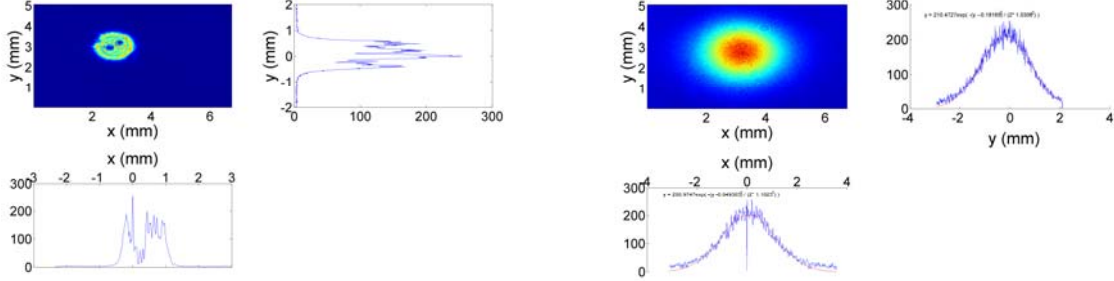


Figure 4 : Left: Image and transverse profile on a CCD of the probe beam. Right: Image and transverse profile of the signal conjugate taken after the beamsplitter with a CCD (as shown in Figure 2).

To further investigate this property a probe beam in the shape of an half-moon was sent, Figure 5. The signal conjugate was then still a Gaussian beam without any default except for a bit of astigmatism in the direction of the half-moon beam. This indicates that the conjugate signal takes the spatial properties of the pump pulses which during filamentation undergoes spatial cleaning, resulting in a clean Gaussian profile. [5]

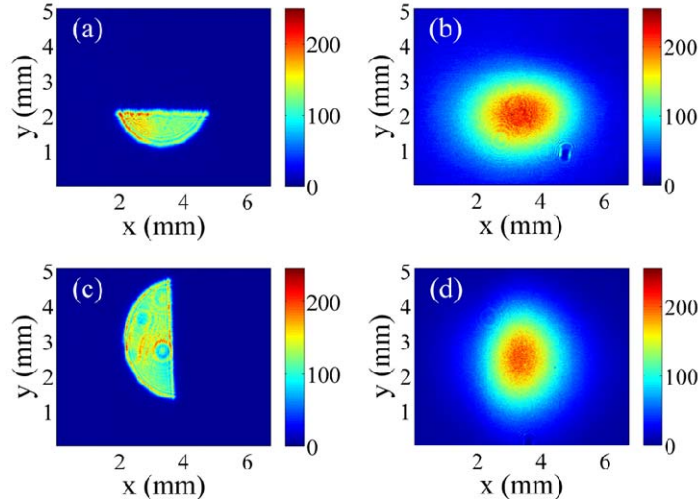


Figure 5 : (a) and (c) are the Image of the incident probe beam and (b) and (d) are the corresponding conjugate beam.

We then investigate the phenomena which is responsible for the creation of such a beam. In order, to ascertain that the conjugate beam is not a simple reflection, we measure the transmitter signal. We place a power meter in the direction of the probe beam after the interaction point of the three take place. We have seen an increase in the energy measured. We can then conclude that the mechanism is based on a degenerative four waves mixing which gives rises to two signal beam, one propagating in the direction of the probe beam and

an another one propagating in the opposite direction of the probe beam. Figure 6 shows the result of the signal energy measure (transmitted and reflected) as a function of the probe beam energy.

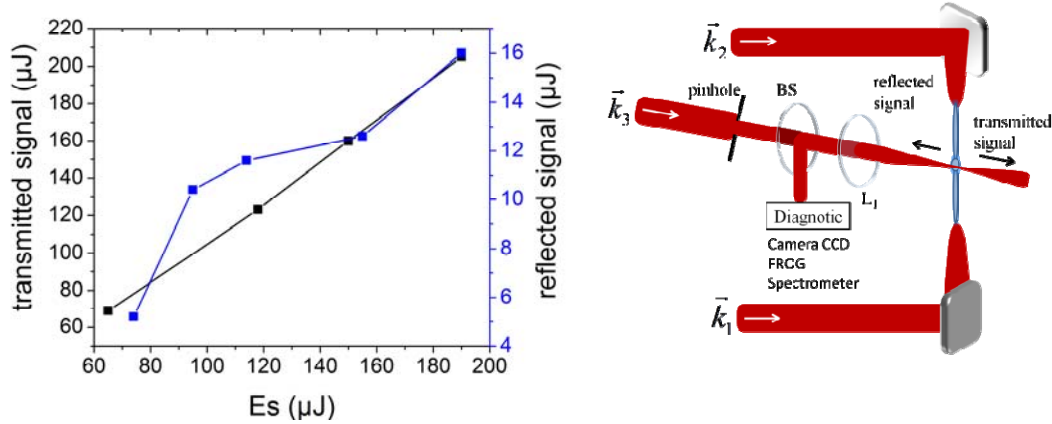


Figure 6 : Energy of the transmitted beam (probe and signal) and Energy of the reflected signal (conjugate) as a function of the probe beam Energy  $E_s$ .

We have also characterized the duration of each pulses, the pump, the probe and the conjugate beam, the results can be seen in Figure 7. The pump pulses were of 71 fs and the probe pulse had a duration of 85 fs. The laser pulses were chirped from 45 fs to 90 fs in order to increase the interaction length between the two counter propagating filament, the difference between the pump and probe beam can be explain by the fact that the pump beam goes through more optics than the probe beam. The conjugate beam was measure to be 60 fs, which corresponds to the duration of the correlation between the two pump beams.

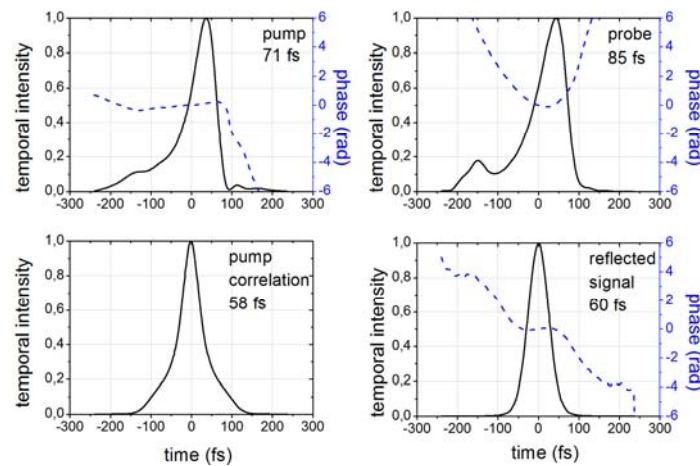


Figure 7 : Pulse duration measurement of the pump, probe and reflected signal with a FROG system. The bottom left graph show the correlation of the two counter-propagating pump.

The efficiency of the interaction was then investigated, and change in the system in order to improve the spatial and temporal overlap of the three beam, such as decreasing the focal

length of the probe beam, increasing the pulse duration of the pump, result in an increase of the conjugate energy, as shown in Figure 8.

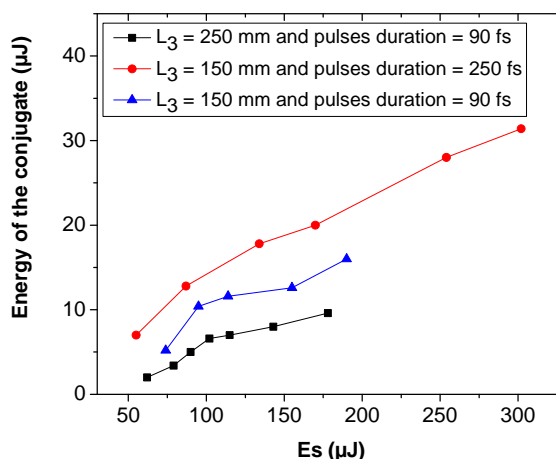


Figure 8 : Energy of the conjugate beam as a function of the probe beam ( $E_s$ ) for different focal length and pulse duration.

## 5/ Schedule and Budget (cost)

The collaboration was a two weeks experimental campaign that took place from 07/16 to 07/27/2012. Dr. Magali Durand was sent to the Laboratory of Applied Optics to work with André Mysyrowicz and his team, Aurélien Houard, Amélie Jarnac, Yi Liu and Bernard Prade.

The cost of this experiments campaign is about 2000 \$, corresponding to plane ticket from Orlando to Paris and public transportation from Paris to Palaiseau for two weeks. Dr. Magali Durand was lodge at a friend place in Paris to reduce cost.

## 6/ Summary

During this collaborative experiment, we were able to obtain optical phase conjugation based on two counter propagating filaments at two different angles of the probe beams. We study the unique characteristic of the phenomena which can create a “clean” Gaussian beam propagating in the opposite direction of the probe beam without. We characterize the efficiency of such a technique depending on different parameters (focal length, energy, pulse duration). Based on the probe beam energy the efficiency was as high as 10 %. We also perform pulse duration measurement contributing to a better understanding of the phenomena.

To conclude by performing optical phase conjugation with two counter propagating filament, we can obtain a “clean” Gaussian profile beam, resulting from the self-cleaning of filamentation, propagating in the opposite direction of the probe beam, which pulse duration is the correlation of the two pump beam. This new method to probe filamentation will help us



better understand the physics of a single filament and also the interaction of two filaments, responding to the Topic 1.1, 1.3 and 3.1 of the MURI “Light Filamentation Science”.

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